STABILITY ANALYSIS OF A TAILINGS DAM-A COMPARATIVE STUDY

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ABSTRACT: Tailings dams are used to impound waste tailings generated by the mining industry. The tailings material is fine grinded particles of sizes similar to clay particles however they behave as cohesionless material. The tailings dam under consideration is a zoned dam raised in six stages using the centre line method and having three different types of fill materials. The zones, from upstream to downstream, are consisted of (i) impervious material (ii) compacted tailings and (iii) pervious random fill. An inclined chimney drain and a connecting horizontal filter are provided to keep most of the dam section on the downstream side dry. The main objective of this study is to perform static and pseudo-static analyses by the Finite Element Method, using the Strength Reduction Technique, and comparing the results with those from various Limit Equilibrium Methods, such as Bishop Simplified, Janbu Simplified, Janbu Modified, Spencer, Corps of Engineers-1, Corps of Engineers-2, Lowe-Karafiath and Morgenstern-Price for both circular and non-circular failure surfaces. The results are presented in the form of normalised plots considering the following cases: (i) Stagewise (Without Tailings) (ii) Stagewise (With Tailings) (iii) Considering circular failure surface, and (iv) Considering non-circular failure surface.

KEYWORDS: Slope Stability, Tailings Dam, Limit Equilibrium Method, Finite Element Analysis, Strength Reduction Method

1 INTRODUCTION

To recover metals and minerals, large quantities of rocks are mined, crushed, pulverized and processed. Hence, the mining industries produce enormous quantities of fine rock particles, in sizes ranging from sand to as low as a few microns. A tailings dam is typically an earth-fill embankment dam used to store byproducts of mining operations after separating the valuable fraction from the uneconomic fraction of an ore. This fine-grained waste (byproducts of mining operations) is known as Tailing, which is frequently released during metals and minerals processing (Mukerjee and Bharathi, 2016).

With the advent of industrialization, large quantities of tailings are being produced and their disposal has become a significant part of the overall mining operation at most hard rock mining projects. The most common method of disposal of the tailings material is by impounding it in slurry form behind embankment dams, generally known as Tailings Dam. Failure of tailing dam can cause widespread damage to the surrounding environment especially if the tailings are from corrosive or radioactive ores, hence its stability is of prime importance for both static and seismic loading.

Duncan (1996) has compared various methods for slope stability analyses and explored their advantages and disadvantages. In this study, the main objective was to perform static and pseudo-static stability analyses of a typical tailings dam by the Finite Element Method (FEM), using the Strength Reduction Technique, and comparing these results with those obtained from various Limit Equilibrium Methods (LEM). The Limit Equilibrium methods used were Bishop Simplified, Janbu Simplified, Janbu Modified, Spencers, Corps of Engineers-1, Corps of Engineers-2, Lowe Karafiath and Morgenstern Price. In LEM, both circular and non-circular failure surfaces have been considered, while in FEM failure surfaces were calculated automatically by shear strain contours. Finite element analyses have been carried out using the geotechnical software Phase^2 (2011), while Limit Equilibrium analyses have been carried out using the geotechnical software Slide (2011).

2 THE TAILINGS DAM

In this study, a tailings dam has been considered, as a zoned dam raised in six stages using the centre line method of construction (EQ (2000 - 9)). It had three different types of fill materials. The zone, from upstream to downstream, consisted of (i) Impervious material (ii) Compacted tailings and (iii) Pervious random fill. An inclined chimney drain and a connecting horizontal filter were provided to keep most of the dam section dry on the downstream side. Fig.1 shows a typical cross-section of the tailings dam showing the different constituent materials. The material properties are given in Table 1.

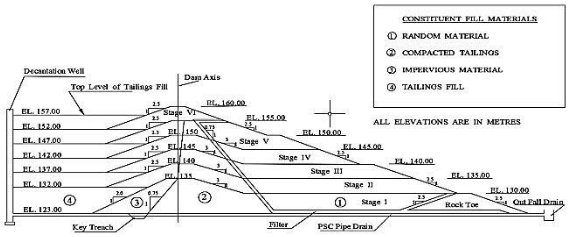

Fig.1: Cross-section of the Tailings Dam

Table 1. Material properties for the constituent fill materials

Soil Type	c (kPa)	ϕ (Deg.)	G (MPa)	υ	γ_b (kPa)
Pond Tailing	0	15	45.64	0.35	19.2
Compacted Tailing	0	26	95.39	0.35	19.2
Impervious Material	14.72	18	53.56	0.40	19.6
Random Material	0	28	190.25	0.30	21.1
Rock Toe	0	28	190.25	0.30	21.1
Foundation Rock	0	28	217.35	0.20	22.2

Tailings dams are constructed in stages. Initially the embankment is constructed upto the first stage height, 12 metres in this case. Then the tailings are deposited, on the upstream side, in the form of a slurry upto the first stage height, 9 meters in this case. Now the dam embankment is raised upto the second stage height, 17 metres in this case. Then the tailings are deposited upto the second stage height, 14 metres in this case. In this manner, the tailings dam is raised in six stages to its full height of 37 metres. The tailings are deposited to a height of 34 metres at the end of the sixth stage. Details of the construction stages can be seen in Fig.1.

3 ANALYSES

The different stages of construction and filling should be reflected in the stability analyses (Rungta, 2016). Therefore the analyses were also carried out for the different stages, with and without the tailings fill for that particular stage of construction. This resulted in 6 x 2 = 12 sets of analyses for each condition considered. The objective of this study was to perform static and pseudo-static stability analyses of the tailings dam described above by the Finite Element Method (FEM) and comparing these results with those obtained from various Limit Equilibrium Methods (LEM). Both circular and non-circular failure surfaces have been considered in LEM. For the pseudo-static stability analysis horizontal seismic coefficient, α_h = 0.06 has been considered.

In FEM analyses the Strength Reduction Technique, where the strengths of the constituent materials are gradually reduced till collapse occurs, has been used, Griffith and Lane (1999) has defined Factor of Safety (FOS) as the factor by which the soil shear strength must be reduced to bring a slope to the verge of failure. Numerically this is represented as,

$$\text{FOS} = \frac{\tau}{\tau_f} \qquad (1)$$

where, τ is the shear strength of the slope material. From Mohr-Coulomb criterion,

$$\tau = \text{c} + \sigma_n \tan \phi \qquad (2)$$

and τ_f is the shear stress developed on the sliding surface. It is given by,

$$\tau_f = \text{c}_f + \sigma_n \tan \phi_f \qquad (3)$$

The shear strength parameters c_f and ϕ_f are given by:

$$c_f = \frac{\text{c}}{\text{SRF}} \qquad (4)$$

$$\phi_f = \tan^{-1}\left(\frac{\tan\phi}{\text{SRF}}\right) \qquad (5)$$

where, SRF is a strength reduction factor. The Limit Equilibrium methods considered were Bishop's Simplified, Janbu Simplified, Janbu Modified, Spencers, Corps of Engineers-1, Corps of Engineers-2, Lowe Karafiath and Morgenstern Price.

4 RESULTS AND DISCUSSION

The stage wise variation of FOS obtained from FEM for all considered cases is shown in Figure 2. In order to compare static and pseudo-static stability analyses results from the FEM, using the strength reduction technique, with those obtained from various LEM, the results were normalised with respect to those obtained from the FEM. These normalised results were then plotted in two groups. In the first group, tailings deposit for the relevant stage of construction was not considered. In the second group, tailings deposit for the relevant stage of construction was considered. Each group was then subdivided into four cases, (i) Static with circular failure surfaces (ii) Static with non-circular failure surfaces (iii) Pseudo-static with circular failure surfaces (iv) Pseudo-static with non-circular failure surfaces. The results and comparisons are shown in Figs. 3 to 6, for the cases where the tailings deposit for the relevant stage are not considered and in Figs. 7 to 10, for the cases where the tailings deposit for the relevant stage are considered.

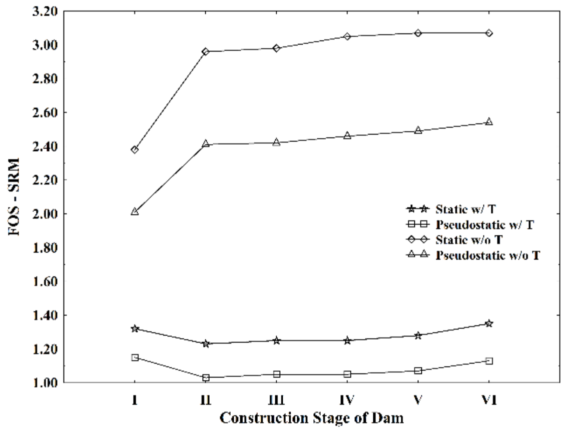

Fig.2 Stage wise variation of FOS obtained from FEM

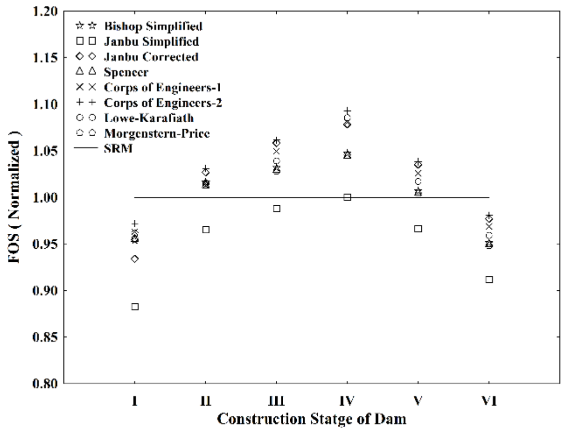

Fig.3 Static analysis without Tailings considering circular failure surface

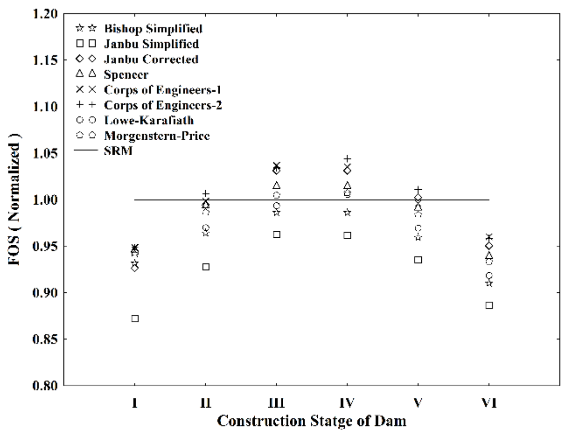

Fig.4 Static analysis without Tailings considering non-circular failure surface

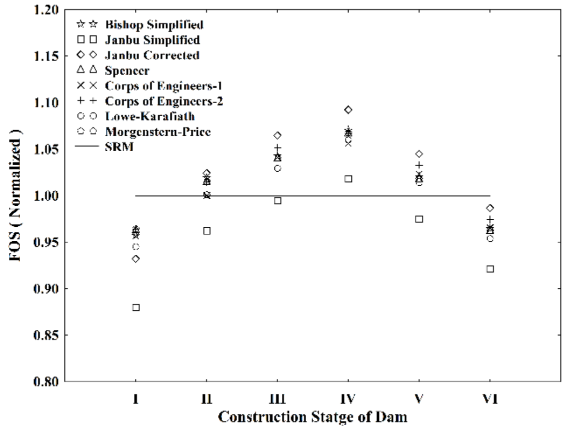

Fig.5 Pseudo-static analysis without Tailings considering circular failure surface

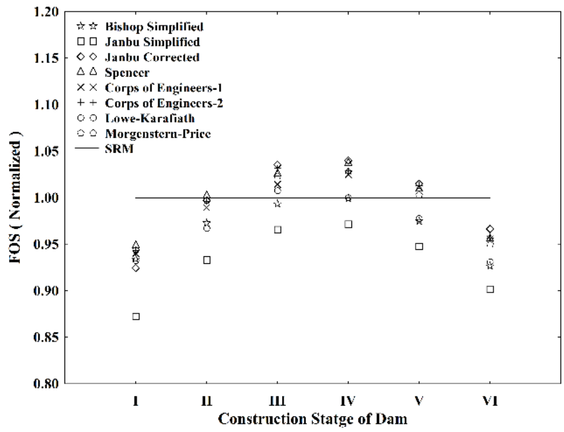

Fig.6 Pseudo-static analysis without Tailings considering non-circular failure surface

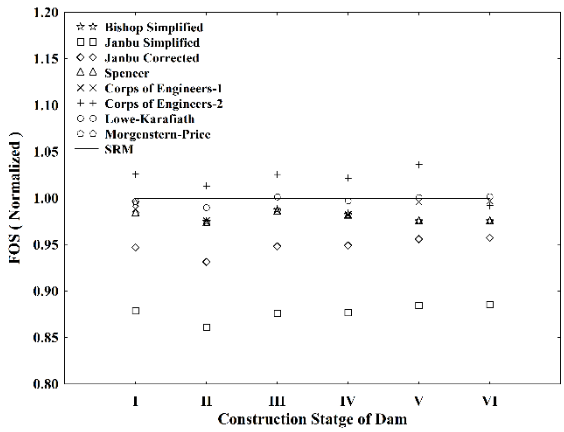

Fig.7 Static analysis with Tailings considering circular failure surface

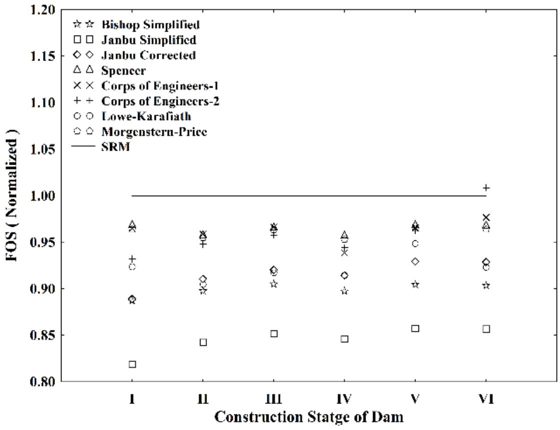

Fig.8 Static analysis with Tailings considering non-circular failure surface

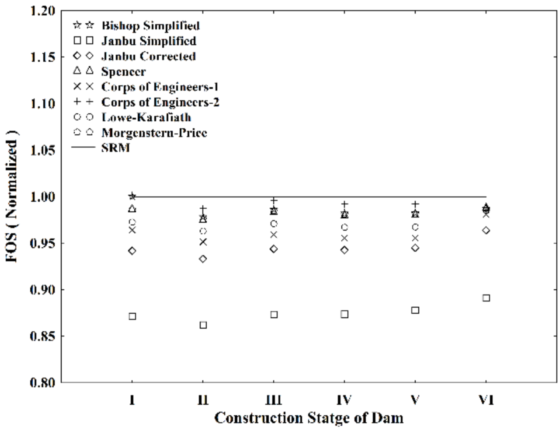

Fig.9 Pseudo-static analysis with Tailings considering circular failure surface

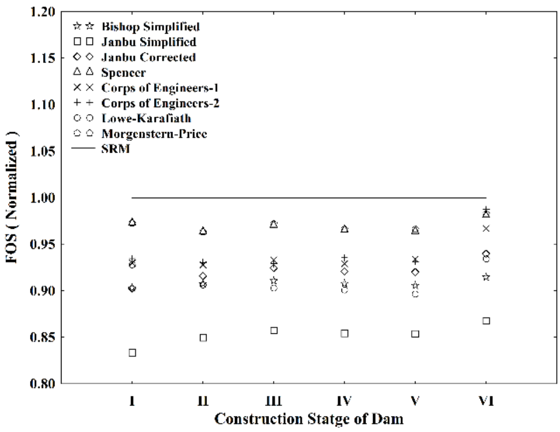

Fig.10 Pseudo-static analysis with Tailings considering non-circular failure surface

5 CONCLUSION

Among the Limit Equilibrium Methods considered in this study, the simplified method suggested by Janbu is the most conservative, as it gives the lowest Factor of Safety. In the Limit Equilibrium Method, considering a non-circular failure surface results in a lower Factor of Safety value, when compared to that obtained considering a circular failure surface. FOS obtained from the Pseudo-static analysis of the dam with Tailings considering both circular and non-circular failure surface gives a lesser FOS value for all considered LEM than FEM. Factor of Safety values, obtained from the various limit equilibrium methods considered in this study, lie within +10% to -20% of the Factor of Safety value obtained from the Strength Reduction Method.

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